EFFECT OF FIBRE HYBRIDIZATION TO THE BEHAVIOUR OF OIL PALM SHELL CONCRETE SLAB

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Abstract

Oil palm shell (OPS) is considered as a waste material originating from the oil palm industry. On the other hand, steel fibre can act as an unconventional material to reduce the sensitivity of OPS concrete. Hybridization of fibre leads to improvements on the mechanical and ductility characteristics of the concrete. In this research, the effect of steel hybrid fibre on the compressive strength and ultimate shear failure concrete slab were studied. Cube compressive strength and combined bending and shear tests for the slab were conducted. OPS that were used are from Kilang Panching while steel fibres are from a factory at Klang. In this study, aspect ratio and volume fraction were emphasized in selecting the most suitable type of steel fibre. The results on the cube compressive strengths shows range of 12.4 MPa – 14.9 MPa, 10.2 MPa – 12.7 MPa and 12.0 MPa – 13.7 MPa for B1, B2 and B3 cubes, respectively. The values were slightly lower than the design concrete strength of 20 MPa. On the other hand, the ultimate shear failure gives range of 36.0 kN – 60.5 kN, 37 kN – 46 kN, 38 kN – 47 kN for B1, B2 and B3 slabs, respectively. As a conclusion, slabs with longest length of steel fibre, SF60 shown better structural performance compared with other length. In terms of hybridization effect, it shows none improvement to the structural slab.

Abstrak

Tempurung kelapa sawit (OPS) dianggap sebagai bahan buangan yang berasal daripada industri kelapa sawit. Sebaliknya, gentian keluli pula boleh bertindak sebagai bahan tidak konvensional untuk mengurangkan sensitiviti OPS konkrit. Penghibridan gentian membawa kepada penambahbaikan kepada ciri-ciri mekanikal dan kemuluran konkrit. Dalam kajian ini, kesan gentian keluli hibrid pada kekuatan mampatan dan kegagalan ricih muktamad papak konkrit telah dikaji. Kekuatan mampatan kiub dan lenturan gabungan dan ujian ricih untuk papak telah dijalankan. OPS yang digunakan adalah dari Kilang Panching manakala gentian keluli adalah dari sebuah kilang di Klang. Dalam kajian ini, nisbah aspek dan jumlah pecahan telah diberi penekanan dalam memilih jenis gentian keluli yang paling sesuai. Keputusan pada kekuatan mampatan kiub menunjukkan julat antara 12.4 MPa – 14.9 MPa, 10.2 MPa – 12.7 MPa dan 12.0 MPa – 13.7 MPa untuk B1, B2 dan B3 kiub masing-masing. Nilai adalah sedikit lebih rendah daripada kekuatan konkrit reka bentuk iaitu 20 MPa. Sebaliknya, kegagalan ricih muktamad memberikan julat antara 36.0 kN – 60.5 kN, 37.0 kN – 46.0 kN, 38.0 kN – 47.0 kN untuk B1, B2 dan B3 papak masing-masing. Kesimpulannya, papak dengan gentian keluli paling panjang, campuran SF60 menunjukkan prestasi struktur yang lebih baik berbanding dengan panjang yang lain. Dari segi kesan penghibridan, ia menunjukkan tiada peningkatan untuk struktur papak.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for testing and Materials
AIV	-	Aggregate Impact Value
BS	-	British Standard
LWC	-	Lightweight Concrete
LWA	-	Lightweight Aggregate
OPC	-	Ordinary Portland cement
OPSC	-	Oil Palm Shell Concrete
OPS	-	Oil Palm Shell
SFRC	-	Steel Fibre Reinforced Concrete
SFRSCC	-	Steel Fibre Reinforced Self-Consolidating Concrete
SF	-	Steel Fibre

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Concrete is the most widely used of construction substantial all over the world. In normal weight concrete, it is made up from cement, coarse aggregates, fine aggregates, water and admixtures. Recent years, oil palm shell (OPS) and steel fibre have taken place as the replaced aggregate and reinforcement inside the concrete. The properties of steel fibre reinforced concrete improved the tensile and bending strength, greater ductility, and greater resistance to cracking and hence improved impact strength and toughness.

In ground-supported slabs, there are two main reasons why steel fibres are used. One of it is to control the development and formation of cracks that is caused by the early age plastic shrinkage and restrained long-term drying shrinkage. Another reason is to provide a degree of post-cracking load-carrying capacity such as the ability of the slab itself to carry load after the first crack has formed during the slab flexure.

Nowadays, lightweight concrete (LWC) has become one of the concrete used in construction. LWCs have many advantages. These advantages include saving on reinforcement, foundation cost, saving on formwork, better fire resistance, durability, heat isolation and frost resistance (Neville, 2008). However, the disadvantages of this concrete included lower mechanical properties and more cement is required compared to the normal concrete, greater shrinkage and higher material cost. Thus, such disadvantages justify the effort to resolve the problems with the existing LWC.

1.2 PROBLEM STATEMENT

Using lightweight aggregate (LWA) in the production of lightweight concrete (LWC) is the most popular method. Common natural LWAs include diatomite, pumice, scoria, volcanic cinders and tuff (Neville, 2008). Other type of LWA that popular in an agriculture field is oil palm shell (OPS). In Malaysia, it has a lot of the residue because Malaysia is one of the world leaders in the production and export of OPS. Generally, the mechanical properties of lightweight aggregate concrete (LWAC) are lower than ordinary concrete (Polat, 2010). One way to enhance the mechanical properties of the LWAC is through the using of steel fibre.

Steel fibre is the most commonly used of all fibre in most structural and non-structural purposes (Mehta and Monteiro, 2006). The addition of steel fibre in LWAC improved the mechanical properties of the concrete especially the tensile strength, impact strength and toughness (Ramados and Namagani, 2008). Steel fibre concretes have much higher fracture energy compared to the plain concrete (Peng et al., 2008).

The approach of using fibre reinforced concrete is expected to be the one of the method that can improve strength of lightweight aggregate concrete. Most research on oil palm shell (OPS) focuses on improving the mechanical properties. Furthermore, only several studies have been conducted or reported on the properties of OPS concrete containing steel fibre. Therefore, this study is conducted to investigate the volume content of steel fibre on the compressive strength and the optimum volume of OPS to be replaced with the coarse aggregate.

1.3 RESEARCH OBJECTIVES

The research objectives are:

i. To study the structural behaviour of oil palm shell concrete (OPSC) slab reinforced with steel fibre.
ii. To determine the effect of fibre hybridization to the behaviour of oil palm shell concrete slab.

1.4 SCOPE OF STUDY

The scopes of this study are:

i. The specimens tested are cubes and slabs; 9 cubes and 3 slabs for each batches with sizes (100 mm × 100 mm × 100 mm) and (350 mm × 500 mm × 100 mm) respectively.
ii. The cement grade used is 20 MPa.
iii. The type of fibre used in this research is steel fibre with L/D ratio is 80, length is 60 mm and the diameter is 0.75 mm with hooked-ends (SF60) and steel fibre with a length of 35 mm, aspect ratio of 65 and the diameter is 0.55 mm with hooked-ends (SF35).
iv. The type of lightweight aggregate used in this research is oil palm shell.
v. Volume fraction of steel fibre used in this research is 1.00%.
vi. The tests that have carried out are:
    i. Cube compressive strength test
    ii. Combined bending and shear test

1.5 RESEARCH SIGNIFICANCE

This study aim is to determine the effect of steel fibre hybridization in order to produce high strength of lightweight aggregate concrete. Essentially, fibres act as crack arrester which is restricting the development of cracks thus transforming in an inherently brittle (Vairagrade and Kene, 2013). For OPS concrete to be accepted for structural application, further investigations need to be conducted to improve the previous researches. Lightweight concrete using OPS as coarse aggregates is able to produce concretes with compressive strengths of more than 20MPa (Teo et al., 2006). Previous research shows that OPS can be used as replacement for conventional stone aggregates in concrete production.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Lightweight concrete (LWC) has become popular in recent years due to its advantages over the conventional concrete. Besides, it gives economical and structural benefits to the construction industry. Modern technology of the concrete also helped in a promotion and application of LWC. The use of aggregates from by-products or solid waste materials from agriculture industries is highly desirable in promoting them as replaced aggregates. Oil palm shell from oil palm industry is used to replace coarse aggregates in this study. This chapter review the information related to the oil palm shell concrete and steel fibre reinforced concrete.

2.2 LIGHTWEIGHT CONCRETE

The advantages of lightweight concrete (LWC) are well recognized in reducing the dead load thus allows for greater design flexibility and cost savings for structural (Alengaram et al., 2013). Using oil palm shell (OPS) in producing LWC is reducing the production cost. The use of alternative materials to replace conventional materials is being an advantage of LWC as OPS made from waste material (Short A, Kinniburgh W., 1978).

Lightweight aggregates such as expanded clay, slate, shale or blast furnace slag is a type of environmental-friendly material that used in the construction industry for making lightweight aggregate concrete (Bremner, 2001). The best alternative to achieve sustainable development of concrete is by use of waste materials instead of raw materials in the concrete mixture (Pelisser et al., 2011). Thus, oil palm shell can be used as it is one of waste material. OPS is generally used as granular filter material for water treatment, floor roofing and road based material (Alengaram et al., 2013).

One characteristics of OPS is; it is lighter than the conventional coarse aggregate. Lightweight concrete that use OPS as coarse aggregate is able produce concretes with compressive strengths of more than 25 MPa (Teo et al., 2005). Mannan and Ganapathy (2004) has studied on structural performance of OPS concrete. A slab with 125 mm thick and length 3.1 m was tested with a live load of 1.5 kN/m^2. It is observed that when load of 8.25 kN/m^2 is applied, the first crack is observed and the deflection was only 9.56 mm compared to an allowable deflection of 12.4 mm. From the result, it can be concluded that OPS can increased the strength of the concrete.

2.2.1 Advantages and Disadvantages of Lightweight Concrete

Lightweight concrete have many advantages compared to the other concrete. Table 2.1 summarized the advantages and disadvantages of the lightweight concrete.

Table 2.1: Advantages and disadvantages of the lightweight concrete

Advantages	Disadvantages
a) Faster and simplest the construction b) More economic in transportation and reduce the forces in work c) Reduce the dead load that directs faster to build and lower cost d) A marked reduction in heaviness of frame structure, foundation or piles e) Easy for do nailing and sawing work compared with conventional concrete f) Do not settle and not required the compaction of the concrete. g) Free flowing and spread freely to fill the voids	a) Slightly sensitive with the absence of water content in the concrete b) Time for mixing is longer compared with conventional concrete. It is to ensure that the mixture was mixed properly. c) Inability to deliver a consistent compressive strengths and density all over the entire area d) Porous and shows poor resistance to heavy scratch. e) Has low tensile strength and thus fracture easily.

Although there are disadvantages due to the use of LWC, it is still preferable in construction industry where the cost can be minimized. However, from the disadvantages of LWC it has made an effort to resolve these problems. The most popular method of LWC production is through the use of lightweight aggregate.

2.3 FIBRE REINFORCED CONCRETE

There are several types of fibre which are natural fibre, steel fibre, synthetic fibre and basalt fibre. Fibre reinforced concrete has gained various attentions in building construction for a couple of years. Fibre such as synthetic fibre liked nylon and polypropylene has excellent resistance of fibre in aggressive environments and it improves post-cracking ductility (Hamoush et al., 2010).

For natural fibre, it can be used in concrete as reinforcement. Reinforced concrete with polypropylene fibres which are used as fibrillated film to increase bond strength with cement matrix is well-established (Hannant et al., 1978). Using shorter fibres with low fibre-content for achieving workability and higher fibre content for better cohesiveness in wet state is recommended.

Ramakrishnan and Ananthanarayana (1968) investigated the ultimate strength and behaviour of 26 single-span beams. It is resulted that the beams failing by diagonal tension when ultimate load using splitting strength is applied. Comparison between theoretical and experimental investigations on the compressive strength and elastic modulus of coir and sisal fibre reinforced concretes for various volume fractions was also carried out by Ramakrishna and Sundararajan (2002). It was observed that both experimental and analytical values of elastic modulus had shown 15% discrepancy, which can be regarded as comparatively small. Ramakrishna and Sundararajan (2002) also suggested based on rheological properties of fresh mortar, it is recommended to use shorter fibres with low fibre-content for achieving workability and higher fibre content for better cohesiveness in wet state.

Toledo Filho et al. (2003) reported their study on development of vegetable fibre-mortar composites of improved durability. Several approaches were proposed to improve the durability of vegetable fibre-cement composites. These included carbonation of the matrix in a CO_2-rich environment; the immersion of fibres in slurried silica fume prior to incorporation in ordinary Portland cement matrix. It was suggested that immersion of natural fibres in a silica fume slurry before the addition to the cement based composites was found to be effective in reducing embrittlement of the composites in the environment.

2.3.1 Steel Fibre Reinforced Concrete

Steel fibres for reinforcing concrete are manufactured from cold-drawn wire, steel sheet and other forms of steel. Most common type of steel fibres used in floors is wire fibre. They vary in length up to 60 mm with aspect ratios from 20 to 100 and with variety of cross sections. Aspect ratio is the ratio of length of fibre to its diameter. It is influenced the properties and the behaviour of the fibre reinforced concrete. Mehrdad Mahoutian et al have proposed that adding of fibres into the concrete is an efficient method of increasing the mechanical properties of concrete. The addition of fibres significantly improves many of the engineering properties of mortar and concrete, and the impact strength and toughness as well.

Figure 2.1: Hook End Steel Fibre

Figure 2.2: Crimped Steel Fibre

There are some types of steel fibre used in concrete. Hook end steel fibre has diameter 4 mm to 1 mm. It tensile strength is more than 1100 MPa with the aspect ratios from 40 to 100. This type of fibre used for shotcreting of underground caverns, tunnel segments, slope stabilization and retaining walls. It is also has high tensile strength which resulted in higher toughness levels. It requires less labour to place concrete compared to the bar reinforcement. The crimped steel fibre has the high dragging resistance strength, which is up to 1100 MPa. It comes in various sizes which are 40 mm, 50 mm and 60 mm and the diameters are 0.5, 0.75, 0.9 and 1.0 with the aspect ratio 40 to 80 (tradeindia.com)

Steel Fibre Reinforced Concrete (SFRC) is a composite material. It consists of hydraulic cements with steel fibres that are dispersed. The steel fibres reinforce concrete superior in withstanding tensile stresses (wiki.org). Therefore, the flexural strength of fibre reinforced concrete is greater than un-reinforced concrete. Other benefits of SFRC are resistance to fracture, disintegration, and fatigue. Bencardino et al. (2008) have studied on the compressive behaviour of steel fibre reinforced concrete. The result from the experiment shows that the toughness of SFRC increases with the product of the volume fraction and the aspect ratio of the fibres.

Recently, steel fibre reinforced concrete has attained acknowledgment in numerous engineering applications. It has become more frequent to substitute steel reinforcement with steel fibre reinforced concrete. The most common applications are tunnel linings, slabs, and airport pavements (brighthubengineering.com).

2.3.1.1 Compressive Strength of Steel Fibre Reinforced Concrete

The compressive strength of concrete is usually considered as the most precious assets in concrete (Neville, 1995).

Chih-Ta Tsai et al. (2003) presents the way durability has been introduced to steel fibre reinforced concrete in Taiwan. It is generally acknowledged that steel fibres are added to improve the toughness, abrasion resistance, and impact strength of concrete. However, a locally developed mixture design method, the densified mixture design algorithm (DMDA), was applied to solve not only the entanglement or balling problem of steel fibres in concrete or to produce steel fibre reinforced self-consolidating concrete (SFRSCC) with excellent flow-ability, but also to increase the durability by reduction in the cement paste content. By dense packing of the aggregates and with the aid of pozzolanic material and superplasticizer (SP), concrete can flow honey-like with less entanglement of steel fibres. Such SFRSCC has already been successfully applied in several projects, such as construction of a low radiation waste container, bus station pavement, road deck panel, and two art statues.

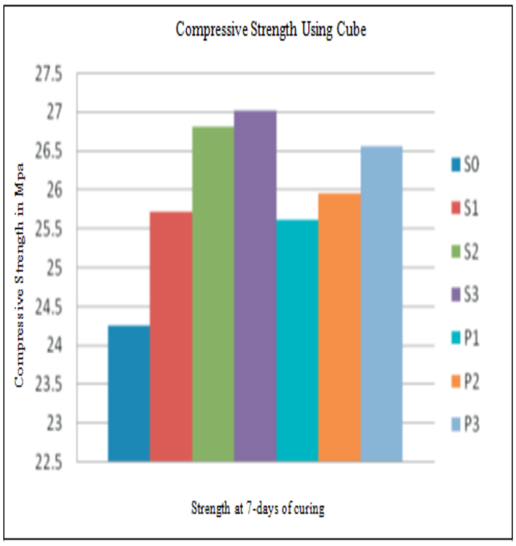
As known, most of the lightweight aggregate concrete is inferior in the tensile strength as well as higher brittleness. Shafigh et al. (2011) have researched on enhancing the compressive strength of oil palm shell concrete (OPSC) by varying the size of the OPS and developed high strength OPSC with a cement content of 550 kg/m^3. It resulted in increasing the compressive strength but however it will be offset by the increased brittleness of the concrete.

Banthia et al. (2007) have been reported that the addition of specified quantity of steel fibres is known to increase the tensile capacity of the fibre reinforced concrete (FRC) along with its post-failure ductility. The post-failure ductility is extremely useful in cases where tensile strength is not adequate to characterize the mechanical response of concrete. After the cracking of matrix, the steel fibres function as a crack bridging mechanism, in which the fibres undergo fibre pull-out, thus delaying the crack formation and limit the crack propagation. De-bonding and pulling out of fibres from FRC require higher amount of energy, resulting in the increased toughness and ductility of concrete.

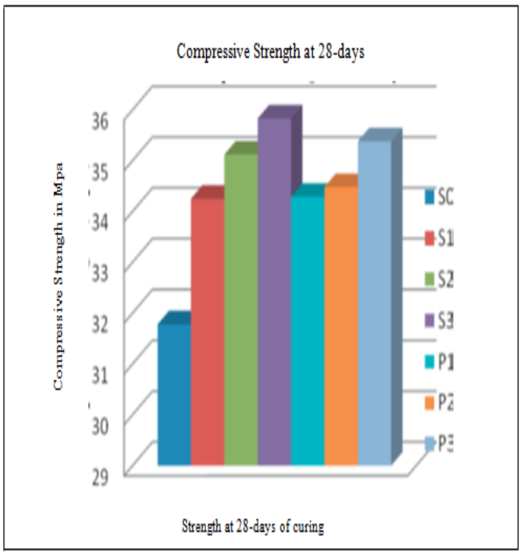
Vairagade and Kene (2013) tested the compressive strength by doing two types of specimens which are cube specimen and cylinder specimen. Compressive strength of control concrete and FRC were calculated by dividing failure load with cross sectional area. It is observed that when fibers in discrete form present in the concrete, propagation of crack is restrained which is due to the bonding of fibers in to the concrete and it changes its brittle mode of failure in to a more ductile one and improves the post cracking load and energy absorption capacity. Result of compressive strength for M-20 grade of concrete on cube specimen with different fibres for different proportions as shown below. S for steel fibre while P for polypropylene.

Table 2.2: Test result of compressive strength using cube specimens

Batch No	Fibre Notation	No of Days	Average Compressive Strength (N/mm²)
1	S0	7	24.26
		28	31.78
2	S1	7	25.72
		28	34.25
3	S2	7	26.80
		28	35.12
4	S3	7	27.01
		28	35.83
5	P1	7	25.61
		28	34.29
6	P2	7	25.95
		28	34.48
7	P3	7	26.56
		28	35.38



(a) 7-days



(b) 28-days

Figure 2.3: Comparison of percentage increase in compressive strength using cube at 7 and 28 days of curing

From figure 2.3, it can be observed that addition of 0.5% 50 mm copper coated crimped round steel fibre having aspect ratio 53.85 with maximum compressive strength in comparison with other steel fibres for both 7 and 28 days of curing. In non-metallic fibres, addition of 24 mm cut length fibrillated polypropylene at 0.4% by weight gives maximum compressive strength with compared to 15 mm and 20 mm cut length. Thus, it can be concluded that compressive strength is dependent on length of polypropylene fibres.

The results of compressive strength using cylindrical specimens are summarized in Table 2.3.